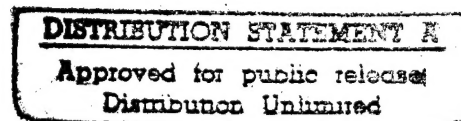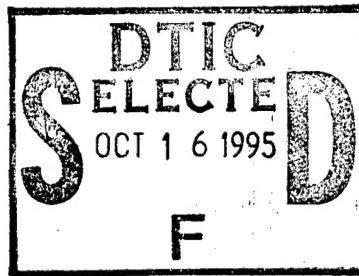# Passive Ranging with Incoherent Systems

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Research Areas Include

• Passive Ranging with a single image from a single-lens incoherent optical system

• Extended Depth of Field Incoherent Optical Systems. (i.e. passive ranging systems that operate over a very large object volume.)

Specific Analysis Includes

• Woodward's Ambiguity Function as an analysis and design tool for incoherent systems.

• Extensions to an Ambiguity function relationship for circularly symmetric incoherent systems.

• Theory of Stationary Phase for the design of phase masks.

• Optimum matching of optical system and digital processing.

• Theory of optimum partitioning of incoherent optical/digital processing.

• Cramer-Rao performance bounds of general incoherent systems.

• Practical CCD sampling and effects on ambiguity function relationships → effect on passive ranging, extended depth of field, and performance bounds.

• Tolerance relaxation through wavefront coding. Tolerance includes that due to misfocus, bandwidth, lens aberrations, and temperature effects.

Spinoff Work Includes

• Design of a practical, known target, three-dimensional passive ranging system. (NASA)

• Collaboration with the Army Research Laboratory on extended depth of field systems. Has led to proof-of-principal experiment. In the process of structuring a joint CU/ARL/Vexcel CRADA.

• Optimum passive ranging to unknown targets via displaced images. (Vexcel Corp.)

• Extensions of passive ranging and extended depth of field to phased acoustic arrays via incoherent ambient noise illumination. This illumination is termed "Acoustic Daylight". (ARL,Scripps Institute of Oceanography)

Publications

- "Wavefront Coding for Incoherent, Object-Insensitive, Passive Ranging". Submitted to IEEE Signal Processing.

- "Extended Depth of Field Through Wavefront Coding". To appear in Applied Optics $\approx$ April 1995.

- "Simple Illustration, Based on the Ambiguity Function, of the Impossibility of Simultaneous Perfect Optical Imaging of Two Different Object Planes". Submitted to Applied Optics

- "An Information Theory Approach to the Design of Incoherent Information Processing Systems". In progress.

- "Woodward's Ambiguity Function in Analysis of Circularly Symmetric Incoherent Optical Systems". In progress.

- "Closed-Form Design of 3-D PSFs via the Method of Stationary Phase", In progress.

- "Optical Tolerance Relation Through Wavefront Coding". In progress.

Example Passive Ranging System

Parameters:
- Field of View = 5° → 100mm focal length
- $f/4$ lens → aperture size of 2.5cm
- CCD undersampling/Low Pass Filtering of 10 times
- Passive ranging mask efficiency of 41%
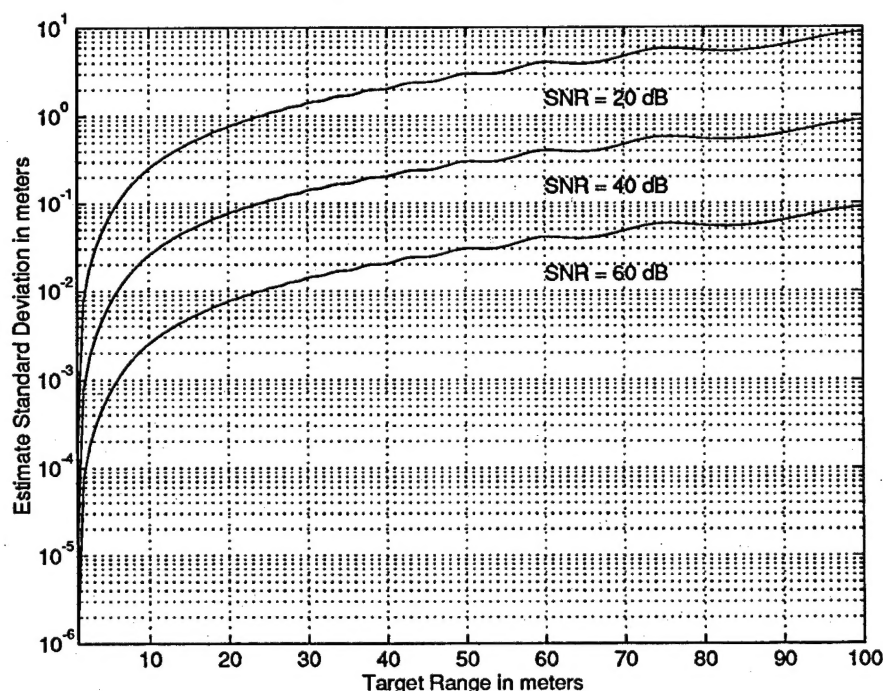
Cramer-Rao Bound on passive ranging to a spatially spectrally white target as a function of SNR (20-60dB) and target range.

Note: For SNR = 60dB, theoretical estimation error can be 1/1,000 or 0.1% with target range of 100m. With a target range of 10m, estimation error can be 1/10,000 or 0.01%.
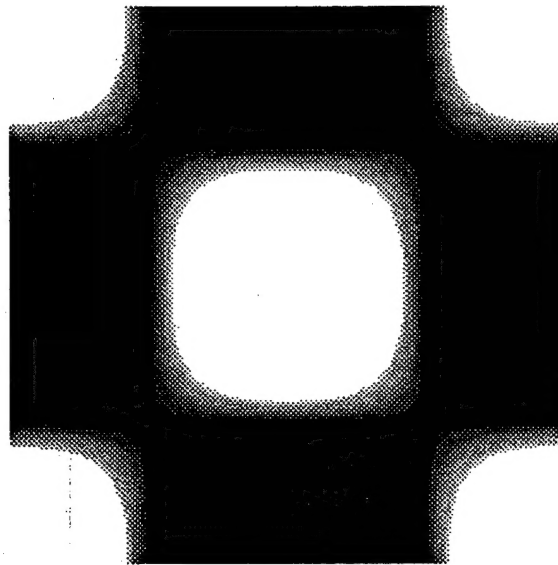
Magnitude of passive ranging mask.

Trade-off Issues:
• FOV can be traded for range and target tilt estimation accuracy
• Sinusoidal estimator complexity can be traded for estimation accuracy.

Potential Problems:
• Mask function is $P(x) = cos(\pi x), |x| \leq 1$. Broadband phase shift system needed.
• Automatic exposure required to maximize SNR without saturation. Saturation leads to increased estimation errors.

Example Extended Depth of Field Imaging System

Problem:

• For sharp imaging between 10m and 1m a standard $f/20$ system is needed.

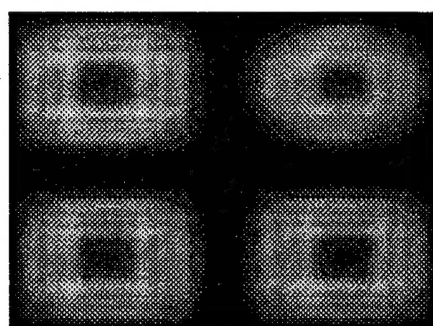• An $f/20$ system captures 100 times less optical power then $f/2$.

Solution:

• Wavefront coding can be used for passive ranging and range independent imaging

• Instead of $f/20$, an $f/3$ system can be used for near diffraction limited imaging from 10m to 1m.
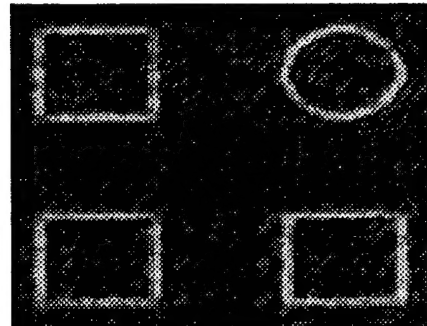
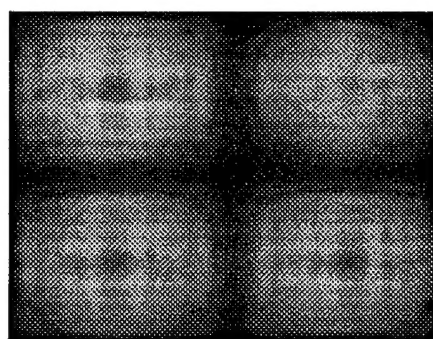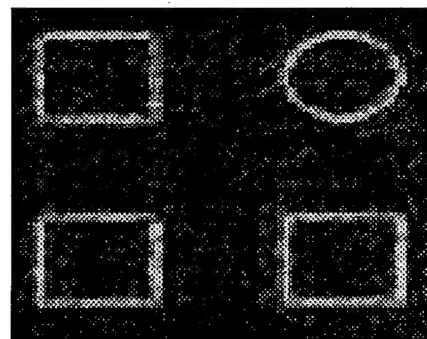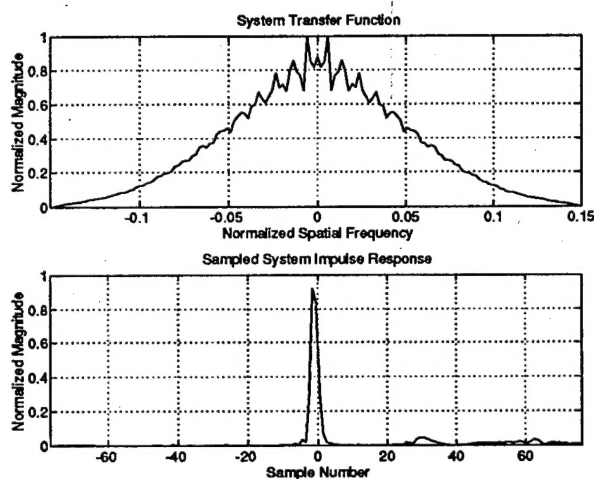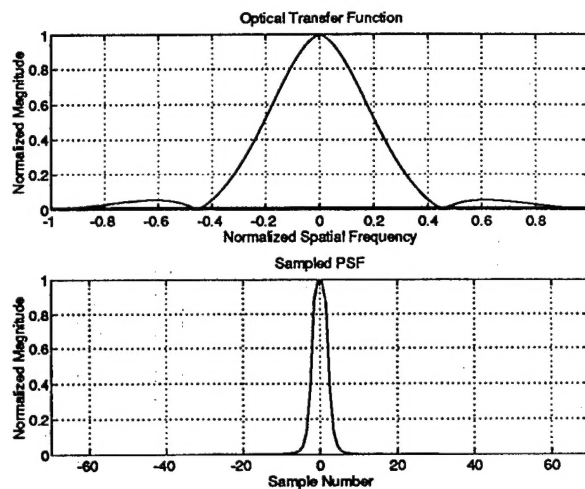• The wavefront coded system is insensitive to bandwidth and thermal changes.
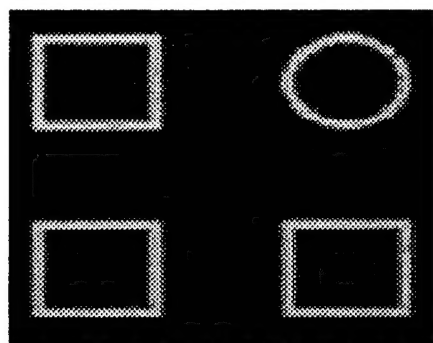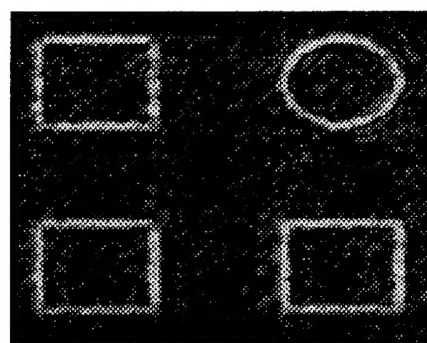
Experimental images from standard optical system (a, c, & e) and cubic-pm optical/digital system (b,d, & f). (a,b) Geometrically infocus, (c,d) mild misfocus, and (e,f) extreme misfocus.
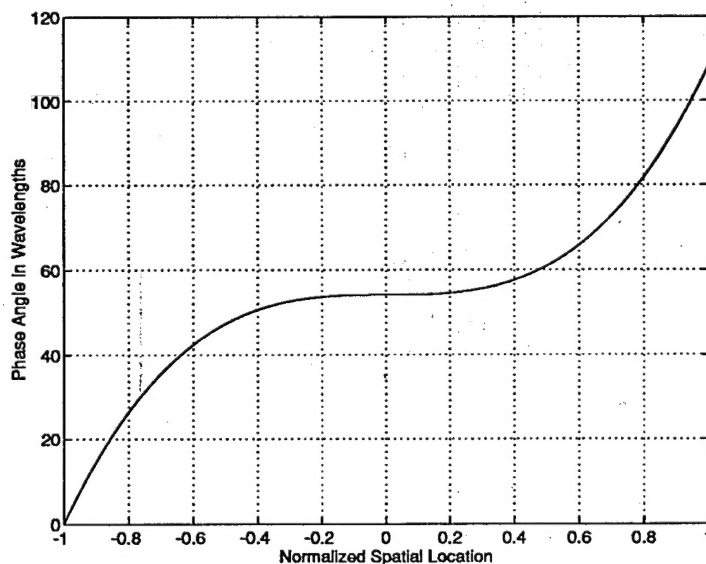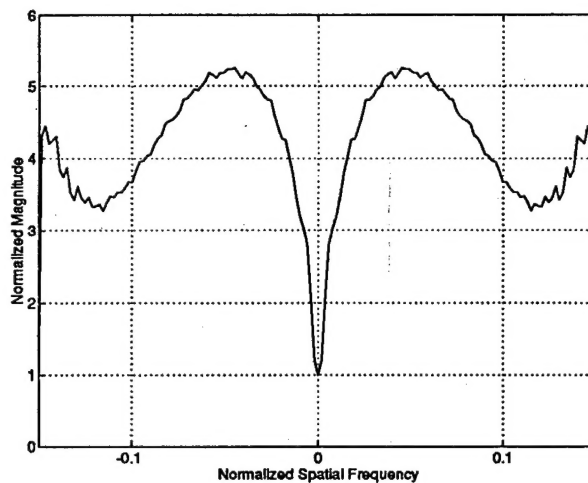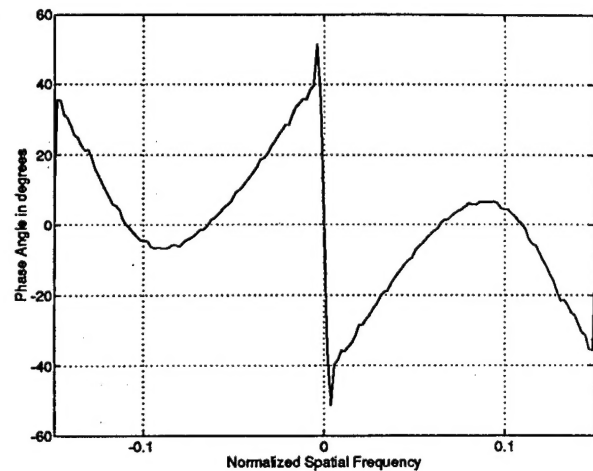
(In conjunction with J. van der Gracht, ARL)

(a)   **(b)**

Comparison of wavefront coded *f*/3 system (a) and standard *f*/20 system (b). Both focused at 1.8m with target at 10m. Notice that the misfocused *f*/20 sampled PSF is wider than the wavefront coded sampled impulse response.

Extended depth of field mask phase in wavelengths.

(a) (b)

Magnitude (a), and phase (b) of digital filter used in example extended depth of field system.

Trade-off Issues:
• Extended depth of field can be traded for larger dynamic range
• Digital filtering complexity can be traded for dynamic range
• Phase deviation of mask related to imaging depth
• Extended depth of field can be traded for multi-spectral imaging
• Extended depth of field can be traded for temperature invariance

Potential Problems:
• Phase mask fabrication is not well understood